PERSONAL ENVIRONMENTS SYSTEMS: ANALYZING THE COSTS AND BENEFITS

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Personal Environments systems are a new approach to workplace comfort, but not a brand new idea. Before modern closed office buildings, people could cool off or get fresh air by opening a window; they could adjust their light using shades, blinds or desktop lamps. Even today, some office workers bring in fans, air filters or radiant heaters to make themselves more comfortable on the job. Simply stated, people who like their surroundings get more work done. Personal Environments systems take that simple concept several steps farther, giving each person control over his or her comfort through a common building system, able to serve both individual offices and open-architecture office spaces.

DEFINING THE CONCEPT

A working definition of Personal Environments is a system that gives the individual office worker the ability to:

1. Select satisfactory environmental conditions

2. At any point in time

3. Through his or her own actions

4. While minimizing use of resources and contributing to the organization's overall effectiveness

The last point is critical. The idea that putting people in control of their environment can enhance business performance is a new and powerful one. Personal Environments will gain wide acceptance when building and company owners are satisfied they deliver net benefits through such measures as energy savings, higher productivity, greater user satisfaction and higher employee retention.

Personal environments are designed for use in both open plan workstations and small closed-door offices. When connected to the HVAC system to supply cooling and ventilation air, Personal Environments provide the conditioning for interior workstations and offices. Perimeter loads require separate treatment, just as they do in a conventional HVAC system.

THE STATUS QUO

Conventional environmental systems are designed to satisfy the "average" person. Zones of conditioned space often serve dozens of people. Yet, no one is "average." People's preferences for temperature, air flow, lighting and acoustic privacy differ greatly, for many reasons, including age, sex, personality, metabolism, allergy or hypersensitivity.[1] For example, older workers typically need more light.[2] Women generally prefer warmer temperatures.[3] In addition, because some employees spend more time at their desks than others, the effects of these comfort variances are not equal.

A NEW APPROACH

Personal Environments systems address the reality that people are unique -- that no single set of environmental conditions can satisfy everyone. Years of study sponsored by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) show that even when all designers, manufacturers and contractors do their jobs right to create a building, the thermal conditioning can be expected to satisfy only 80 percent of the occupants (ASHRAE Standard 55-92).[4]

Individual problems with lighting, acoustics and air quality add significantly to dissatisfaction with office environments. High levels of dissatisfaction have been documented by a number of organizations through studies using both questionnaires and on-site measurements. For example, a study by the University of California at Berkeley has shown dissatisfaction rates of 35 percent in office settings.[5]

CONTROLLING THE ENVIRONMENT

A complete Personal Environment system integrates thermal comfort, air movement, lighting, acoustic privacy and air quality in a single unit under individual control. Its functions include:

1. Delivering filtered air to the desktop

2. Selecting the air flow rate and direction

3. Selecting the air temperature

4. Providing heat for legs and lower body from a radiant heat panel

5. Selecting the intensity of task lighting

6. Selecting the level of background noise masking

The system also provides occupancy sensing to shut down lighting, radiant heating, background noise masking, and air flow when the space is vacant, thus saving significantly on energy.

BEYOND VAV

Personal Environments systems differ fundamentally from conventional ceiling air delivery systems. A conventional system (Figure 1) delivers air from the ceiling, normally through Variable Air Volume (VAV) distribution. The system relies on the velocity of the air from the ceiling diffusers to drive supplied air into

the workstations. The system is usually split into multiple workstation zones for thermal and lighting purposes. Each zone -- typically covering 7 to 10 cubicles plus empty and common areas -- is conditioned to a "compromised" set of conditions with the goal of keeping a majority of occupants comfortable. Fresh supply air is encouraged to mix with the ambient air in pursuit of a uniform set of environmental conditions. This requires considerable air flow.

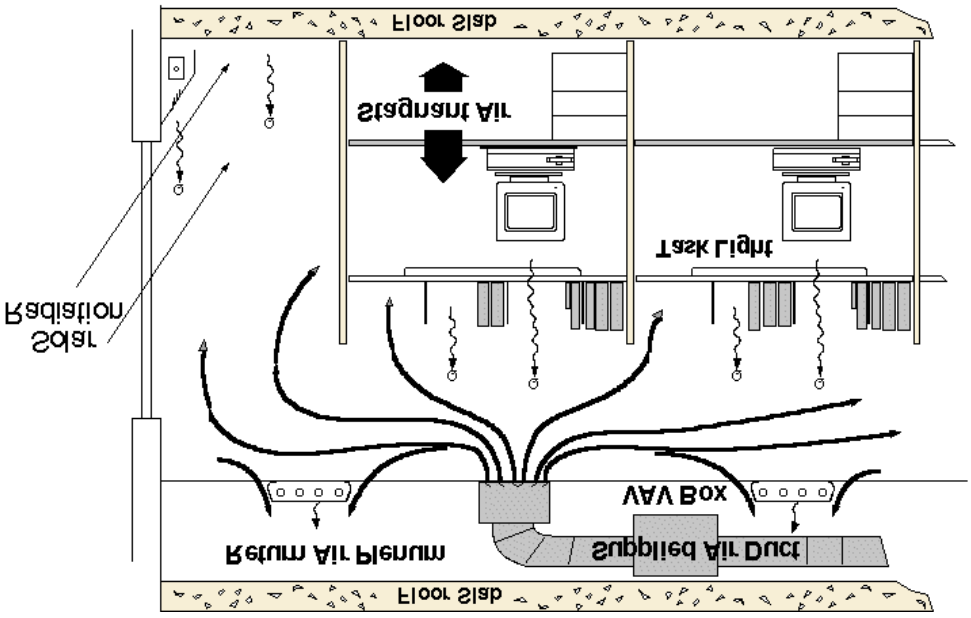


FIGURE 1 CONVENTIONAL OFFICE

Besides the obvious drawbacks of seeking an "average" level of comfort, conventional systems raise performance issues.

1. The natural convection of heated air from the workstation is up, or opposite the direction of the supplied air. The supplied air must overcome this convection. This may result in a relatively stagnant air layer between the breathing zone and the top of the workstation panels.

2. The configuration of workstations with respect to the ceiling diffusers may result in air being directly forced into some workstations, and essentially missing others.

3. Air entering the room from the ceiling and returning via the ceiling will short cycle -- some percentage of the cooled and fresh air does no useful work. Depending on the design, this may be true of up to 50 percent of the air supplied to the office area.

PERSONAL ENVIRONMENTS SYSTEMS: ADVANTAGES

A Personal Environments system introduces only as much air as the occupants request for thermal conditioning and ventilation and delivers the air directly to the user. Stale air, which is purged from the occupied space, migrates through the common areas and travels into the return air system. There, a

conventional central unit conditions, filters or exhausts it. If floor or ceiling diffusers are not used, then the temperature in common areas represents the average of what the office occupants request, plus or minus any thermal loads the air may be carrying to the return system. Localized loads can be specifically dealt with or exhausted appropriately.

Personal Environments systems have the advantage of 100 percent ventilation effectiveness. All air is introduced to the occupied zone, defined by ASHRAE as from .076 meters to 1.82 meters above the floor. None of the air short cycles to the return air plenum -- it must pass through the occupied zone first.

AIR DELIVERY

Air in a Personal Environments system can be delivered to workstations through a supplied air plenum beneath a raised floor (Figure 2), or through a ceiling/wall plenum delivering air to office spaces in a spine configuration (Figure 3). In either case, supplied air enters the work space at or near floor level and is ducted to a fan and electronics unit installed beneath the desk.

Air Delivery with Raised Floor

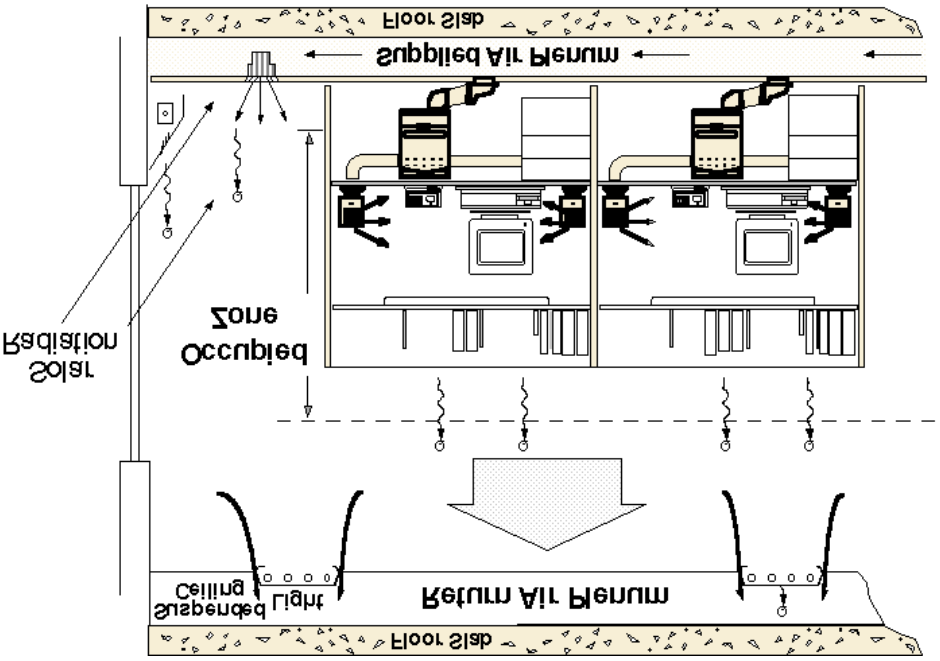


FIGURE 2 PERSONAL ENVIRONMENTS: RAISED FLOOR AIR SUPPLY

Distribution through a raised floor is generally advantageous in new construction and some major renovations. Air is supplied to the floor plenum at approximately 25 Pa, generally from a number of VAV boxes controlled by static pressure rather than temperature.

The raised floor maximizes office design flexibility. Work spaces can be easily moved or reconfigured, especially if telecommunications and electric power are also run beneath the floor.

Air Delivery with Wall Plenum

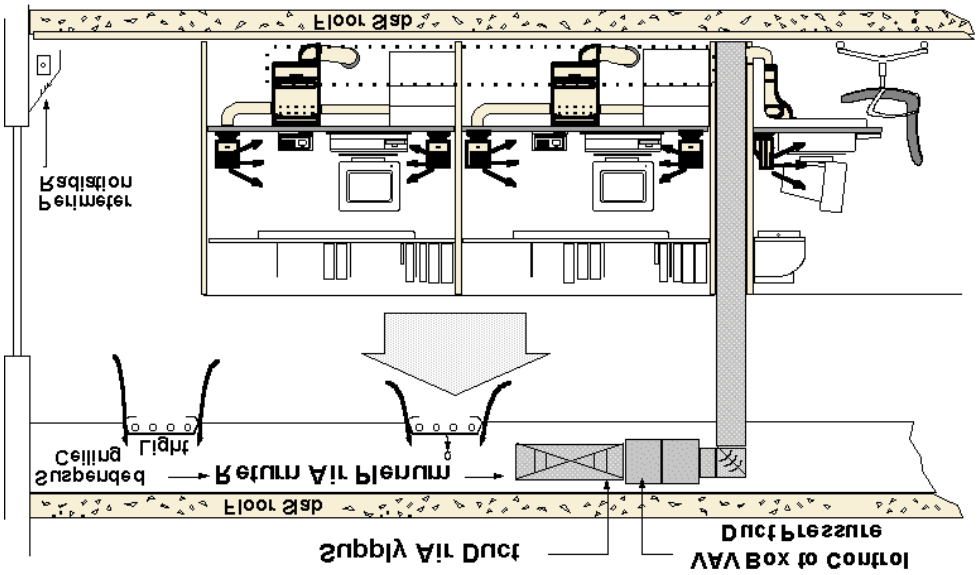


FIGURE 3 PERSONAL ENVIRONMENTS: CEILING OR WALL AIR SUPPLY

Distribution through a wall plenum is generally advantageous in retrofit projects. Wall plenum systems are typically used when:

1. There is no raised floor, or the raised floor does not include air delivery.

2. The office plan is to maintain the workstations on a spine arrangement. That is, though offices may change sizes along the spine, there will be no changes to the spine. This approach is often planned in conjunction with cabling and networking.

3. The air to the Personal Environments plenum is provided through a VAV box located in the ceiling and accessed from a wall or vertical duct or provided from the floor below through penetrations in the floor slab.

TWO KINDS OF SYSTEMS

There are two basic types of Personal Environments systems. The components of each are shown in Figure 4 and Figure 5. They are:

1. Supplied air, in which conditioned air from the HVAC system is delivered directly to the work space.

2. Circulated air, which is not connected to the HVAC system but provides air circulation under the worker's control.

Supplied Air

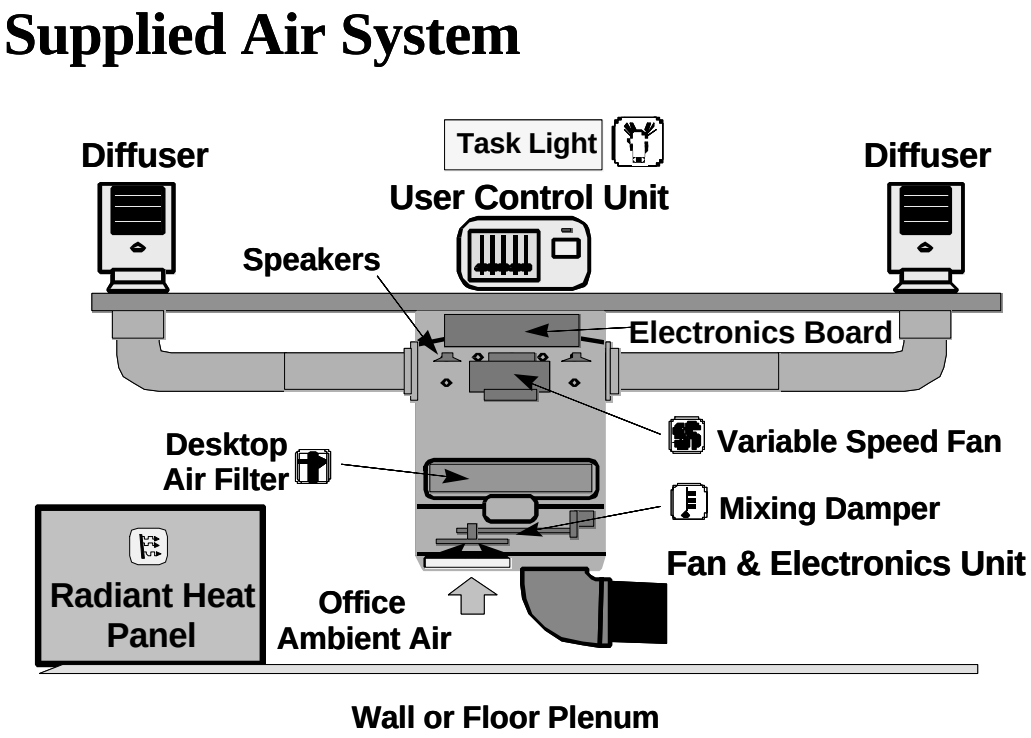


FIGURE 4 PERSONAL ENVIRONMENTS: COMPONENTS OF SUPPLIED AIR SYSTEM

Supplied air delivers the full benefit of a Personal Environments system, providing both temperature control at the desktop and outdoor air directly to the person's breathing zone. Temperature control is provided by mixing supplied air from the HVAC system with office ambient air in a ratio set by the office worker, through the desktop control unit. The ambient air passes through a particle filter as it enters the fan and electronic unit. The mixed air then passes through the desktop filter, which is an electret particle filter.

Supplied air systems are generally best suited for new construction, in which the entire HVAC system can be configured for the concept. These installations may provide the lowest first cost in addition to the full benefits in productivity, energy savings and user satisfaction. Supplied air can also be highly cost-effective in major renovations. The largest installations of supplied air systems include:

1. West Bend Mutual Insurance in West Bend, Wis., where a new office building constructed in 1991 has 470 units on a raised floor delivery system.

2. S.C. Johnson Wax in Racine, Wis., where a new Commercial Markets building completed in 1997 includes 480 units, also on a raised floor system.

Circulated Air

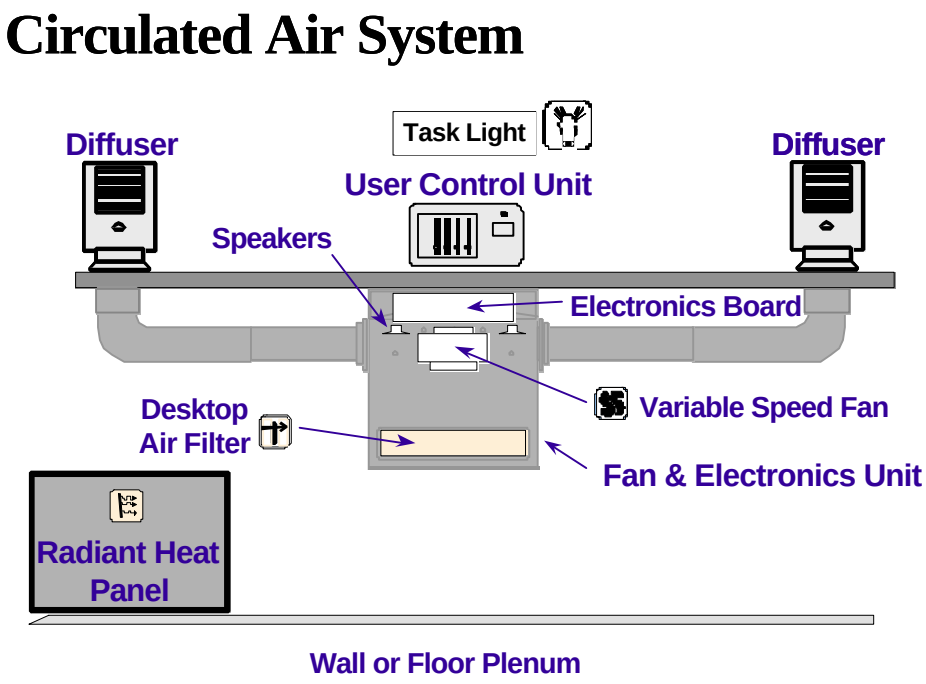


FIGURE 5 PERSONAL ENVIRONMENTS: COMPONENTS OF CIRCULATED AIR SYSTEM

Where delivery of supplied air to each workstation is difficult or impractical, circulated air systems offer all the benefits of Personal Environments except temperature control. The circulated air system draws air from beneath the desk, filters it, and distributes it to the desktop. The occupant can control thermal comfort by adjusting the volume and direction of air flow.

Circulated air systems are suited for situations like:

1. Open plan architecture offices in new buildings and renovated buildings where there is a problem moving air into the work space from ceiling diffusers, and where there is a wide variation in thermal loading in individual workstations.

2. Areas of existing open architecture offices, such as near a perimeter, where there is a wide range of thermal conditions and where the selection of air flow, radiant heat and task light helps compensate for changing conditions.

One large pharmaceutical company installed 869 circulated air units in a new building where high office partitions were used to increase work privacy. These partitions reduce air flow in the workstations from the ceiling diffusers. The Personal Environments system provides the necessary air circulation, plus control of other environmental functions in an integrated and visually appealing unit.

COSTS AND BENEFITS

At first glance, Personal Environments may appear cumbersome to design and costly to build and maintain. In practice, the concept can save money at every step. By far the biggest benefit of Personal Environments is higher productivity from employees who feel comfortable and have direct control over their office environment conditions. Based on conservative estimates, productivity gains alone can provide payback in one to two years, or less. However, Personal Environments systems also can reduce HVAC installation costs, save on energy, and reduce employment costs by increasing employee retention. Building management also becomes more efficient because the systems sharply reduce complaints about temperature and ventilation, typically the source of more than 70 percent of calls to maintenance staff. Relief from these calls frees staff to focus on more productive matters.

FIRST COSTS

Experience from the West Bend Mutual and S.C. Johnson Wax buildings shows that the installed cost of an HVAC system designed around Personal Environments, when applied in new construction, is comparable to and may be less than that of a conventional VAV system. This includes the cost of the Personal Environments unit. The primary savings are:

1. Reduced requirement for supplied air system duct work

2. Elimination of most VAV boxes and ceiling diffusers

3. Reduced HVAC fan requirements for air distribution

4. Reduced HVAC capacity because air delivery and cooling requirements are decreased

This comparison does not include the cost of a raised floor, generally $54 to $75 per square meter or about $1,050 for each 14$m^2$ workstation. However, the raised floor can provide immediate cost savings as a route for installing cable, network and electrical distribution systems. This configuration also provides savings over the life of the building by reducing the cost of office moves and the cost of changing network cabling as technology changes.

A study of the installed cost of Personal Environments in a retrofit application using an office spine arrangement showed that the supplied air system cost somewhat less to install than a conventional ceiling delivery system (Table 1). In these cases, the cost of the Personal Environments unit was an addition, increasing the net cost per workstation by $900 to $1,500. Figure 6 shows a typical distribution duct system.

TABLE 1 INSTALLED COST COMPARISON:
PERSONAL ENVIRONMENTS VS. TRADITIONAL SYSTEM

Personal Environments system costs (9 workstations):	
Ductwork, workstation to workstation	$1,117
Ductwork, VAV box to fire damper	220
Fire damper	150
Spin-in fittings (9 @ $20)	180
Hole in structural floor	150
VAV box	150
Pressure controller	300
TOTAL	**$2,267**
Traditional System Costs Eliminated (service to 9 workstations):	
Ductwork (VAV box to diffusers)	$1,092
Flex duct	224
Slot diffusers (4 @ $120)	480
Spin-in fittings (4 @ $20)	80
VAV box	150
Thermostat	400
TOTAL	**$2,426**
Difference (Conventional ceiling air delivery minus air delivery to each workstation) $2,426 - $2,267 =	$159
Savings in cost of air delivery to each workstation $159/9 workstations =	$17.68
Additional cost of Personal Environments unit:	$900 to $1,500

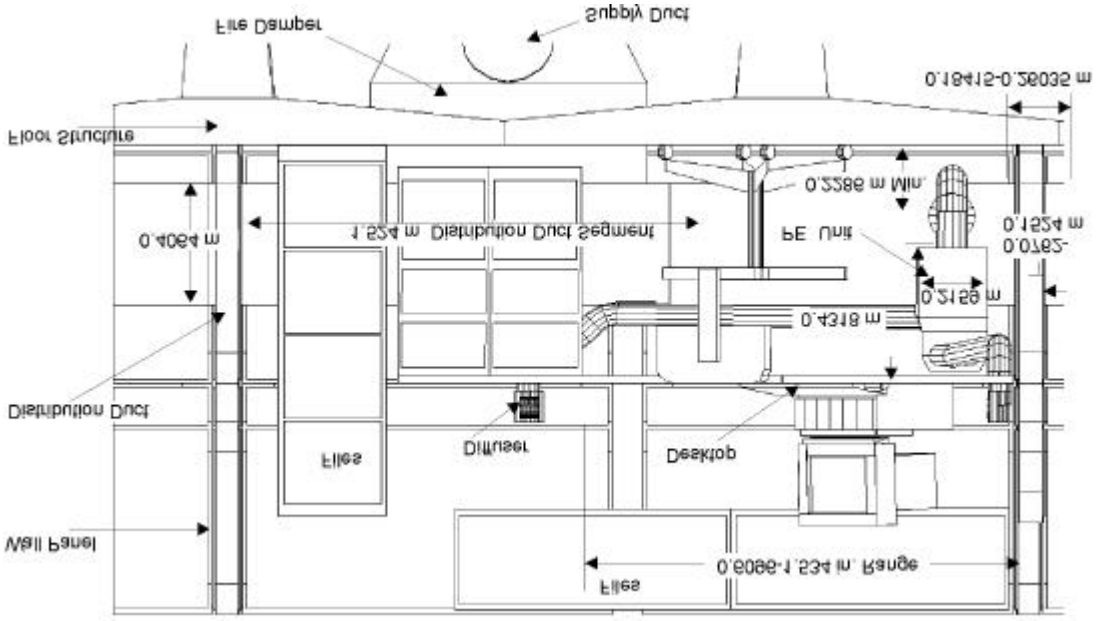


FIGURE 6 PERSONAL ENVIRONMENTS DISTRIBUTION DUCT SYSTEM

ENERGY COSTS

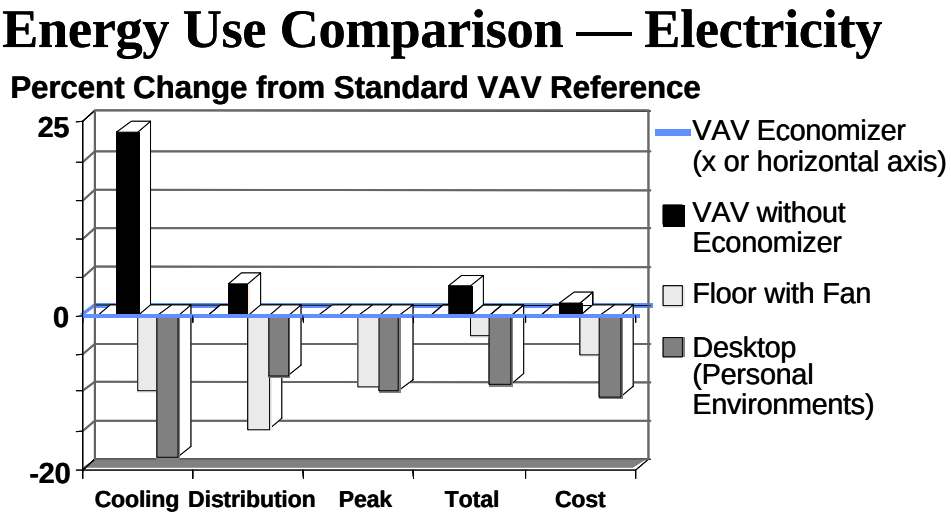
Personal Environments systems provide significant opportunities to save energy and reduce building operating costs. Central to the system's energy-saving capability is the occupancy sensor, which essentially shuts the unit down whenever the work space is vacant for approximately 15 minutes. Additional energy savings result from reduced cooling load, higher unoccupied space temperatures and higher supplied air temperatures, as detailed below. Table 2 shows typical electricity usage by a single Personal Environments unit.

TABLE 2 ELECTRICITY USAGE - PERSONAL ENVIRONMENTS SYSTEM

	Minimum		**Maximum**	
	Current (Amperes)	Power (Watts)	Current (Amperes)	Power (Watts)
Fan motor	0	0	0.2	30
Task lighting (max. 2 lights)	0	0	1.7	100
Radiant heat panel	0	0	1.4	170
Background noise masking	0	0	0.02	2
Electronics	-	5	0.1	10
Communication controller	0	0	0.04	5
TOTALS	**-**	**5**	**3.46**	**317**
Watts/square meter (2.4 m x 3.0 m office)		0.1		44.02

Note: The actual net power demand is 217 watts because task light loads are present with or without the use of Personal Environments.

Simulation studies by three universities have projected energy savings at 8 to 18 percent using Personal Environments versus conventional systems. The University of Reading projects an energy use reduction of 15 percent.[6] Carnegie Mellon University's simulation predicted 8 to 15 percent savings.[7] Through a contract with the California Energy Agency, the University of California at Berkeley conducted a DOE II simulation that compared a conventional VAV system without economizer, a VAV system with economizer, a Personal Environments system, and floor tiles with fans (to move air into the office space[8]). The results showed that Personal Environments would reduce the cost of operation for office electricity and environmental conditioning by approximately 12 percent (Figure 7).



(Based on UC Berkeley Study for the California Institute for Energy Efficiency; DOE II Simulation for Fresno, CA Building; CERD-02-94; July 1994)

FIGURE 7 ENERGY USE COMPARISON: ELECTRICITY

Personal Environments save significant central fan energy because the system operates at very low pressures. A typical under floor plenum static of 12.5 to 37.5 Pa is considerably less than the

187.5 to 250 Pa to which most VAV ducts are controlled. This translates directly to central fan kilowatt savings. Fans in VAV boxes also can be eliminated because Personal Environments fans distribute air to occupied areas. Personal Environments also contribute to energy efficiency in other ways, including:

1. Occupancy-based electricity usage. Fifteen minutes after office worker leaves the space, the occupancy sensor automatically reduces powered functions to their lowest levels, turning off the task lighting, local fan, radiant heat panel and background noise masking and adjusting the damper to reduce supply air to the minimum. Surveys show that work areas are unoccupied 20 to 30 percent of the time.

2. Reduced cooling load. The reduction in electrical usage through occupancy sensing reduces internal heat gains in those areas, lessening cooling requirements all the way back to the chiller.

3. Higher unoccupied space temperatures. Common areas and corridors within the office area can be allowed to rise to higher temperature, because employees have access to cooled air in their work spaces, where they need it.

4. Higher supplied air temperatures. Air can be delivered from the HVAC system at higher temperatures than normally required, because the conditioned air is delivered directly to the office worker's upper body, and because the air blowing on the office worker has an added cooling effect.

COST OF EMPLOYMENT

Personal Environments can contribute to positive attitudes of workers toward their job and their employer, helping reduce turnover and absenteeism. Improvements in these areas reduce the cost of employment. Studies have shown that the cost of hiring a clerical worker is approximately $6,000. West Bend Mutual calculates that for a knowledge worker, such as a claims processing staff member, the cost of replacement can be as high as $58,000 if all factors of lost work, search, screening, hiring and training time are considered.

A 1988 study by Texas Instruments determined that offices with higher environmental quality do result in reduced turnover.[9] A KIRCO Realty and Development study of office workers established the relationship between office area environmental quality and turnover, showing a 6 percent advantage for quality offices.[10]

In addition, Personal Environments can directly benefit indoor air quality, a significant factor in worker satisfaction. In an October 1996 article in Indoor Air Quality Update, "IAQ and Productivity: How Much Does Poor Air Quality Cost?" the costs of absences, health costs, quality of work and employee attitude were among the factors considered in assessing the costs of employment.[11]

By putting individuals in control of their environmental conditions, and providing them the ability to create air movement within the workstation, Personal Environments reduces the likelihood of indoor air quality complaints and the associated costs -- as well as reducing liability exposure on indoor air quality issues.

Many studies by NIOSH (the National Institute of Occupational Safety and Health) and others have shown that lack of air movement and effective ventilation are the cause of approximately 50 percent of indoor air quality complaints. Through the air flow and temperature control features of Personal Environments, and through the increased filtration of air at the workstation, the cause of many indoor air quality complaints is significantly reduced.[12]

EMPLOYEE PRODUCTIVITY

By far the greatest savings from Personal Environments systems come through higher productivity from workers who feel comfortable and can control their own office environments. In the past 15 years, dozens of studies of productivity in the workplace show that people respond very differently to their environment. Small changes in productivity can make big financial differences. Based on the results of studies over many years, productivity gains expected from eliminating environmental stress range from 3 to 15 percent.

Employee salaries are by far the highest cost of a building. For example, the cost per square meter of salaries in an average facility is anywhere from 86 to 139 times the cost per square meter of building operations. Salary costs often top $2,153 per square meter, per person, per year.[13]

A simple projection of impact is that a 1 percent productivity increase among workers in a 46,451 m^2 building can mean the equivalent of $975,000 per year in salaries (Table 3). Thus a 3 percent gain in productivity yields a business impact of $2,925,000 per year.

TABLE 3 SAMPLE CALCULATION: BUSINESS IMPACT OF GAINS IN PRODUCTIVITY

Data	
Average salary + benefits	$29,250
Size of workstation	13.94 m^2
Productivity gain	1%
Building size	46,451.5 m^2
Calculation	
1. $29,250 salary /13.94 m^2 =	$2,098.30 per person/ m^2
2. 1% x $2,098.30 =	$20.98 productivity increase/ m^2
3. $20.98 productivity increase/m^2 x 46,451.5 m^2 =	$975,000
A 3% increase in productivity would lead to a benefit of:	$2,925,000 per year.

NETWORKING OPTIONS

Personal Environments can be connected to Facilities Management Systems to provide additional features and increased performance for supplied air systems. Capabilities of network connections include:

1. Providing morning warm-up or cool-down control strategies

2. Interfacing with other air handling control strategies

3. Monitoring worker selections for temperature, air flow, radiant heat and task light

4. Monitoring occupancy status

5. Providing occupancy override so that a workstation can be disabled when the occupant will be out of the office for extended periods

Among many benefits, data from network connections can be used to set supply (or discharge) air temperature to maintain conditions that meet occupant requirements, and to set supply air to maintain minimum energy use.

A CASE HISTORY

In 1991, West Bend Mutual Insurance in West Bend, Wisconsin, constructed a new office building and installed Personal Environments systems in 360 work spaces (that number has now risen to 470). For its own purposes, the company had maintained productivity data for each of its office staff members for a number of years. Staff functions included insurance applications and claims processing and purchasing. In addition to

Personal Environments, the new building featured other advanced office attributes, such as network applications, cafeteria, worker drycleaning dropoff-pickup room, and workout room.
To learn more about the impact of an advanced office environment, the company worked with Johnson Controls and Pacific Gas and Electric to support a productivity and building quality study carried out by Rensselaer Polytechnic Institute.[14] The study looked at productivity and environmental effectiveness in the new building versus the old.

The productivity showed a clear 16 percent increase in the new building. A test procedure using statistical analysis methods showed that the Personal Environments systems alone accounted for a 2.8 percent productivity increase. Company managers felt the actual increase was closer to 5 or 6 percent. Productivity dropped 12.8 percent when the Personal Environments systems were disconnected as a test. Using the conservative 2.8 percent productivity gain, savings amounted to $260,000 annually, based on the company's $13 million salary total. The Personal Environments systems paid for themselves in less than two years.

West Bend Mutual realized other benefits from Personal Environments, including:

1. Reduced building operating costs. West Bend Mutual reported that complaint calls related to the building environment dropped from an average of 40 per week in the old building to fewer than two per week in the new building, at a savings of $75 to $300 per call. Operating staff time dropped 20 percent because staff had fewer hot and cold calls.

2. Energy savings. As a component of a highly efficient all-electric building, Personal Environments contributed to significantly lower energy costs. Energy use in the new building is approximately $\$1.08/m^2$/month, versus $\$1.94/m^2$/month in the old building.

3. Employment costs savings. West Bend Mutual human resource staff have established that turnover and absenteeism have decreased in the new building, and interviews with office workers have shown that the quality of environmental control provided by the Personal Environments systems is a factor.

4. Office flexibility. The company has found it easy to reconfigure office space to accommodate changes in staffing. Up to 30 percent of office space has been changed in a given year without requiring changes in the HVAC system.

LONG-TERM ISSUES

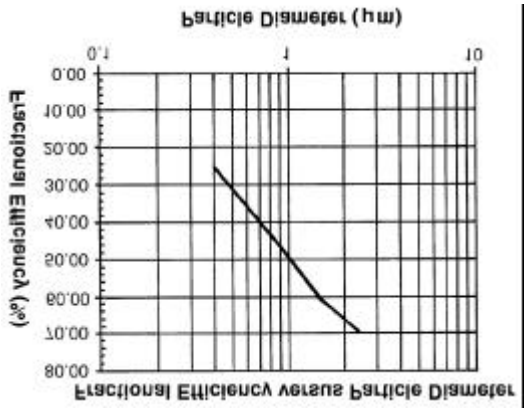
While new to the HVAC industry, Personal Environments systems show promise of low long-term ownership and maintenance costs. The systems do add mechanical and electrical equipment to the work space, but the design minimizes maintenance and is more flexible.

The office units are simple and designed for high reliability. The fan is a quiet ball bearing design with an expected life comparable to that of a conventional HVAC central fan system. The air mixing damper components have been tested for extended service life. The desktop air diffusers and the user control unit are manufactured from durable injection molded plastic.

Filters require periodic checks and replacement. The recommended practice is to inspect filters every six months and replace as needed. Filters can be changed either by office occupants or by maintenance staff. Filter locations are shown in Figure 4 and Figure 5.

The ambient air filter is a particle filter, effective for particles greater than 5 microns and for fibers. Its primary purpose is to keep carpet fibers and particles generated by feet movement from entering the Personal Environments air stream.

The desktop air filter is a 70-weight electret particle filter, using charged fibers to attract and hold particles, which generally have an electric charge. The charge on the fibers is part of the manufacturing process. There is no electrical connection to the filter; it is not an electrostatic filter. Its average characteristic are summarized below in Figure 8.



Desktop Air Filter Efficiency (as tested by LMS Technologies, Inc.)

Size Range (μm)	Fractional Efficiency (%)
0.3-0.5	26.10
0.5-0.7	34.97
0.7-1	44.77
1.0-2.0	60.10
2.0-3.0	71.43

FIGURE 8 PERSONAL ENVIRONMENTS ELECTRET FIBER DESKTOP AIR FILTER
FILTER EFFICIENCY (AS TESTED BY LMS LABORATORIES)

CONCLUSION

Personal Environments systems can be a highly cost-effective alternative to conventional HVAC systems for open architecture office spaces. The systems offer competitive installed costs, simple design, and high flexibility leading to lower churn costs for space reconfiguration. These benefits, combined with savings on employee productivity, energy usage, building operations and employment cost, make these systems a potentially attractive option for both new construction and retrofits.

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